Effects Of Climate Change On Alpine Plant Species at Finse, Southern Norway

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Preface

This is my master thesis for the conclusion of my master program at the Institute of Ecology and Nature Resource Management at the Norwegian University of Life Sciences, 2012.

The writing of this thesis has faced many challenges. Much of the work involved practices and methodologies which were new for me, such as all measurements of functional traits and statistics. It was a daunting challenge, but because of that, I have learned much and I am deeply grateful.

Firstly I would like to thank my supervisor Kari Klanderud for all help, field assistance, and patient guidance. I also had the good fortune of having such a good supervisor who cared so much about my work. Further words of gratitude go to Siri Lie Olsen for her guidance and helping me with statistics. Third, I would like to thank Brian Moore for checking my grammar. And finally, I would like to thank the Finse Research Station for its generous hospitality.

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Abstract

The issue of climate change is one of the most discussed topics on Earth. The Earth is warming up and that is expected to continue in future. Alpine vegetation has already been affected by climate warming and has already shown responses. This study examined the effects of elevated temperature on individual functional traits. Because the temperature seems to be a crucial indicator of future existence and diversity of alpine plant community, I assessed how the functional traits of 10 selected plant species responded to enhanced temperature and evaluated which of these functional traits act as more important in comparison to others. Open-top chambers (OTCs) were used to simulate climate warming and selected functional traits were measured, elaborated and evaluated. The most of species showed a significant increase in height under simulated warming suggesting that this functional trait may be the most plastic. *Carex capillaris, Thalictrum alpinum*, *Antennaria dioica* and *Festuca vivipara* responded most strongly to experimental warming by significant difference in height in OTCs plots compared to control (C) plots. *Carex capillaris* responded the most to simulated climate warming in OTCs plots showing in addition to the height, a significant increase in both length of the longest leaf and leaf area. Grasses *Carex capillaris* and *Festuca vivipara* showed a significant increase in height under simulated warming in contrast to *Luzula spicata* belonging to graminoids also, suggesting the findings from previous studies that not all species within a functional type will respond to warmer temperature similarly.

Contents

Introduction

The recent rate of temperature increases, because of climate change, is the highest in the world`s history; and the effects of climate change are truly alarming (McMullen et al. 2009). The world has been warming for over one hundred years and will presumably warm in the future as a direct effect of industry, forest destruction, and agriculture (NSF 2009).

Alpine plants are considered to be highly sensitive to global environmental change (e.g. Pauli et al. 2003; Beniston et al. 1995) because they are limited by low temperatures. Hence, mountain ecosystems can be used as a sensitive ecological indicator of climate change.

High mountain areas, as well as areas of high latitudes, are regarded as the regions with the greatest increase in temperature in the last half century (Walther et al. 2005). Temperature is subsequently one of the major limiting factors with regard to plant growth and development. Alpine plants may be easily outcompeted by thermophillic species; cold tolerant plants normally found in alpine regions might be pushed out of their habitats by warm-loving plants, and that may lead to a decrease in biodiversity (Michelsen et al. 2011).

Not all species within a functional type will react similarly to climate change, and it is therefore important to identify individual responses. For instance, tall growing plants (Klanderud 2008) may respond positively to climate warming in comparison with low stature species. The individual responses will, however, vary across climate zones, functional groups and over time (Arft et al. 1999).

There is a wide variety of correlations between individual plant traits (Weiher et al. 1999). Functional traits can help to describe the ecology of species (Nicotra et al. 2010) using a few, easily quantifiable variables. The distribution of plants is related to their adaptation to ecological conditions. This ability can be related to morphological or physiological properties. Thus, by studying the species and their traits in several environments (Pelissier 2010), we can estimate the response of traits to environmental changes.

Alpine vegetation has already responded to warmer temperatures and thus the signs of climate change can already be observed (Rammig et al. 2010).

What we do know is that in some areas, some high-altitude species have decreased in abundance at lower –elevation sites and have increased in abundance at the highest altitudes (Klanderud and Birks 2003). Consequently, the species that move upwards may cause a gradually increasing level of competition among plants leading to decrease in abundance of less competitive species (Klanderud and Birks 2003).

Hence, it is important to take into account that the new climatic era will have its “winner” and “loser” species. The aim of this study is to examine what makes some plant species win this battle while others lose under global warming by selecting certain plant species and their following particular study.

This is done by selecting 10 plant species and studying the effects of experimental warming on their functional traits, in order to detect which functional traits are more important than others in response to climate warming.

The specific research questions addressed in this study are the following:

(1) What are the effects of climate warming on functional traits of selected plant species?
(2) Which functional traits are more important than others in terms of climate change?

Materials and methods

Study area and sampling method

The study area is at Finse, northern part of Hardangervidda, in the alpine region of southwestern Norway, where the Finse Alpine Research Center is also situated. The mean monthly temperature during the summer is 6.3 °C and the annual temperature is -2.1 °C (Aune 1993). The mean monthly precipitation at Finse is 89 mm (The Norwegian Meteorological Institute 2010).

The study was performed in a *Dryas octopetala* heath at ca 1550 m elevation on Sandalsnuten at the turn of July and August 2011. This study area is located in the middle alpine region where the dominant species is the dwarf shrub *Dryas octopetala* (Klanderud and Totland 2005). Other commonly occurring species of this area are *Bistorta vivipara, Carex rupestris, Carex vaginata, Saussurea alpine* and *Thalictrum alpinum*.

To examine the effects of climate change on plant communities, an experiment with open top chambers (OTCs) was established in the *Dryas octopetala* heath on Sanddalsnuten in July 2000. Eighty plot-pairs were randomly established in the *Dryas* heath. Each plot-pair consists of two 30x60 cm plots separated by a ca 10 cm wide row while each plot-pair consists of two plots divided into eighteen 10x10 cm subplots (see Klanderud and Totland 2007).

Open top chambers are commonly used to raise the temperature. OTCs minimize secondary experimental effects, such as changes in atmospheric gas concentrations and ambient precipitation, although they might reduce wind (Hollister and Webber 2000).

The OTCs experiment at Finse is part of the International Tundra Experiment (ITEX), which is trying to predict how arctic and alpine plant communities cope with global warming. The specially designed structures act like open-topped greenhouses, increasing the internal temperature by an average 2.5 °C.

Plant trait data

The study species were chosen according to a previous study, where 27 species were added as seeds inside and outside OTCs (Klanderud and Totland 2007). Klanderud and Totland (2007) examined in above mentioned study the relative importance of seed availability and different biotic and abiotic factors for maintaining the diversity of an alpine plant community. In their study, some of the species managed to survive and germinate four years after seed addition treatment under both ambient and elevated temperature conditions, whereas others were not observed in plots after four years treatment, or found in very low abundance. From those species, I selected ten plant species that responded differently under the climate warming, i.e. *Cerastium alpinum*(forb), *Erigeron uniflorus*(forb), *Parnassia palustris*(forb), *Carex capillaris*(graminoid), *Potentilla crantzii*(forb), *Thalictrum alpinum*(forb), *Antennaria dioica*(forb), *Luzula spicata*(graminoid), *Bistorta vivipara*(forb) and *Festuca vivipara*(graminoid). Summarily, 7 nonlegume forbs and 3 graminoids were chosen.

It is very important to measure traits on robust, well grown plants, preferably in completely unshaded conditions (Weiher et al. 1999). This can be especially important for some leaf traits that are very plastic in response to light (Cornelissen et al. 2003). Therefore, the selected individuals were adult plants, always the largest, green, healthy and the finest species within the plot.

The control and open top chambers plots where the plants were sampled from, were chosen randomly. Each plant species was supposed to be collected from 10 different control plots and 10 different OTCs plots, i.e. 20 samples per one species. Thus, the expected number of all plant samples was 200. However, not all plant species were abundant enough to be sampled in the stated number.

The species were sampled within 8 days and predetermined functional traits were measured in the laboratory according the handbook for standardised and easy measurement of plant functional traits (Cornelissen et al. 2003). The measured traits were the following: height, length of the longest leaf, amount of leaves, amount of fruit/seeds, and amount of flowers. *Carex capillaris, Luzula spicata* and *Festuca vivipara* were the only species where the fruit/seeds were observed and therefore counted only within those species. All of the above-mentioned traits were measured either in the laboratory or directly in the field if the weather allowed. Afterwards, all the specimens were pressed in the laboratory at the Alpine Research Centre at Finse.

In the laboratory of the Norwegian University of Life Sciences (UMB) at Ås, the leaf area of one leaf of each plant species was measured, whereas only the largest green and undamaged leaves were measured. The leaf area was measured by a leaf area meter. I measured every leaf multiple times to ensure the accuracy of the measurement. The whole plant samples *were dried at 60*°C for 48 hours and weighed right after in order to get the measurements of the whole-plant biomass and the leaf biomass. Finally, I calculated the specific leaf area (SLA) by dividing the fresh leaf area by its oven-dry mass (Vile et al. 2005). Correlation of all functional traits was done in order to evaluate the strength of the relationship between variables.

Statistical analyses

One-way analyses of variance (ANOVA) was used to test the effects of climate warming (OTC) on the different functional traits (response variable), i.e. the height, length of the longest leaf, amount of leaves, amount of fruit/seeds, amount of flowers, leaf area, biomass and specific leaf area. All statistical analyses were conducted with the Minitab Statistical Software.

Results

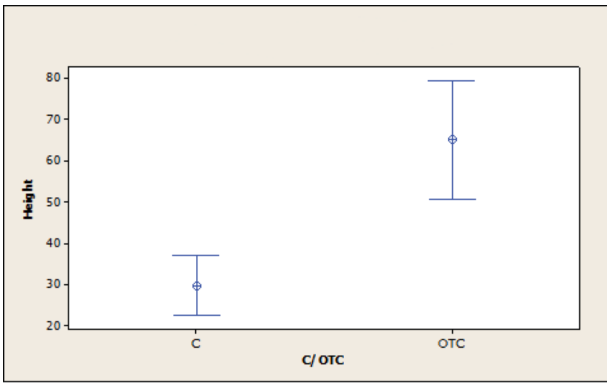
The total number of presented study species is 9 (see Table 1). *Erigeron uniflorus* was found in only three samples in OTC plots and no one from C plots. Therefore, the statistics could not be done for this species. Altogether, 140 plant individuals were collected and all the data were elaborated.

Species responses

The responses of simulated climate warming differed among species. The results show that species respond to climate warming most by growing taller, showing a great difference in comparison with the individuals growing under ambient conditions. *Carex capillaris, Thalictrum alpinum, Antennaria dioica* and *Festuca vivipara* all demonstrated a significant positive response in height in OTCs compared to control plots (see Figure 1).

Figure 1. Results of one way ANOVAs on the effects of climate warming on height in C vs OTCs plots at alpine Finse for species: *Carex capillaris* (Fig. A) *Thalictrum alpinum* (Fig. B), *Antennaria dioica* (Fig. C), and *Festuca vivipara* (Fig. D).

A



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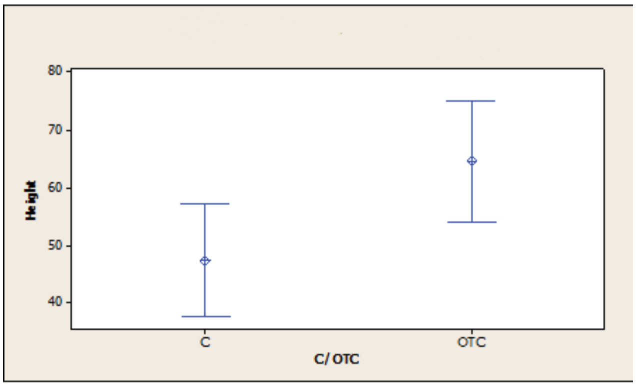

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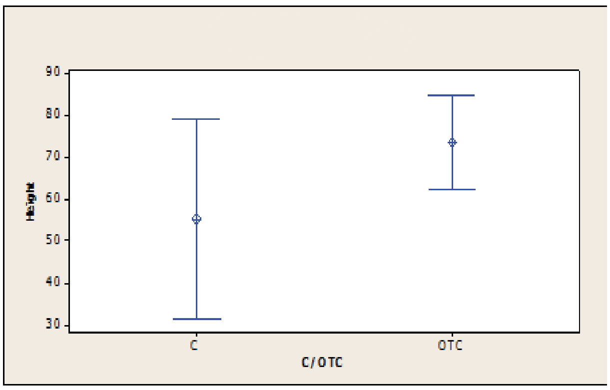

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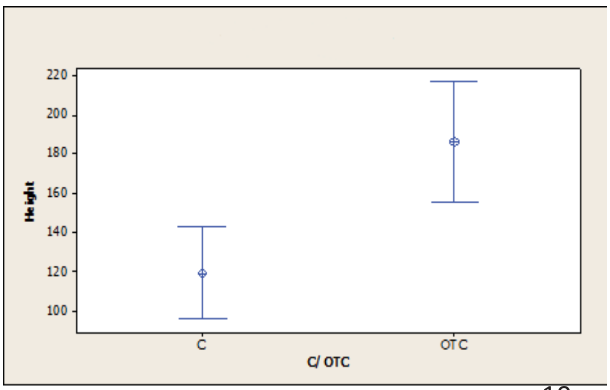


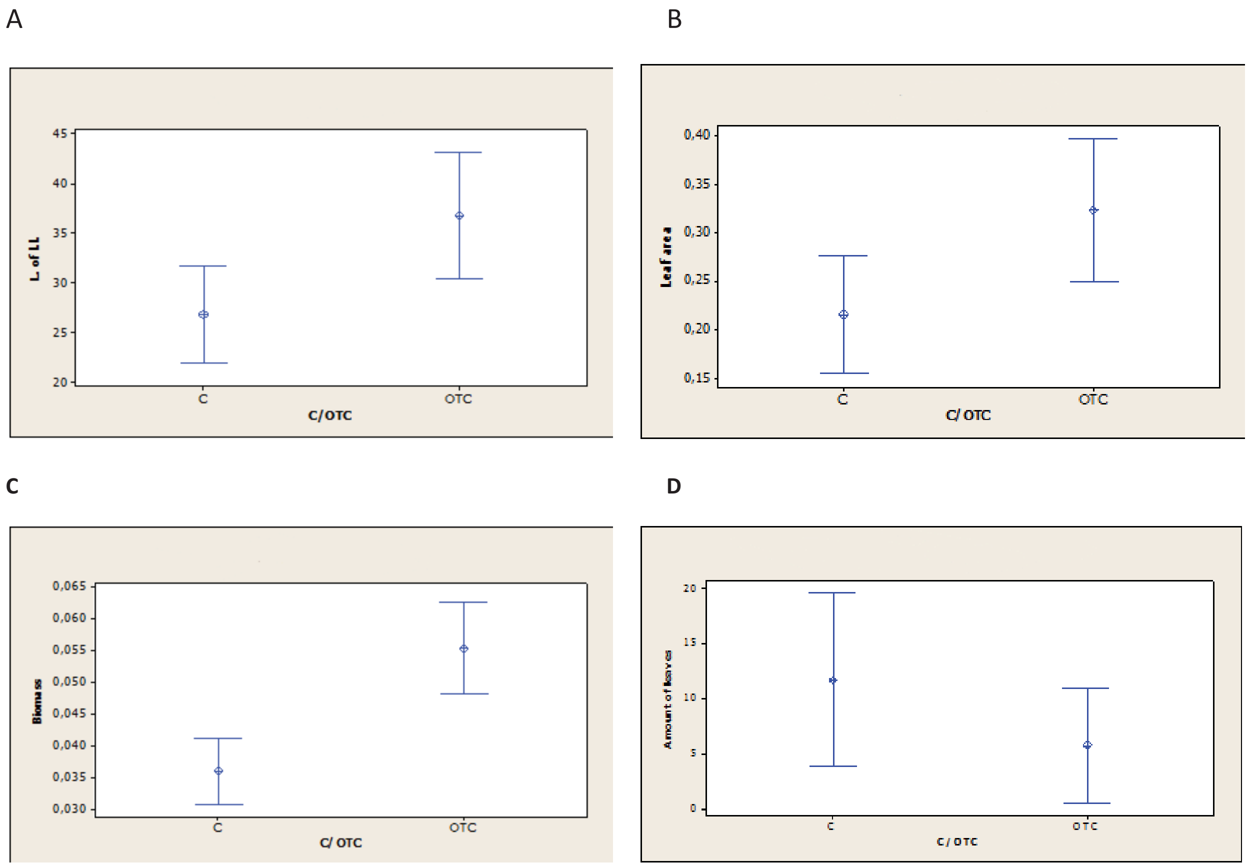
Table.1 Results of one way ANOVAs on the effects of climate warming in control (C) and open top chambers (OTC) plots on different functional traits on nine selected plant species at alpine Finse.

Species	Height		Length of the longest leaf		Number of leaves		Number of fruit/seeds		Number of flowers		Leaf area		Biomass		Specific leaf area	
	F_{df}	P	F_{df}	P	F_{df}	P	F_{df}	P	F_{df}	P	F_{df}	P	F_{df}	P	F_{df}	P
Cerastium alpinum	$0.01_{1,7}$	0,919	$0.00_{1,70}$	0,969	$4.09_{1,7}$	**0,089**			$1.00_{1,7}$	0,356	$0.22_{1,7}$	0,653	$0.09_{1,7}$	0,780	$0.07_{1,7}$	0,795
Parnasia palustris	$2.83_{1,3}$	0,234	$0.52_{1,30}$	0,546	$1.00_{1,3}$	0,432					$7.25_{1,3}$	0,115	$0.46_{1,3}$	0,567	$2.46_{1,3}$	0,257
Carex capillaris	$16.97_{1,15}$	**0,001**	$6.51_{1,15}$	**0,023**	$0.65_{1,15}$	0,435	$1.53_{1,15}$	0,236			$5.43_{1,15}$	**0,035**	$1.00_{1,15}$	0,333	$2.67_{1,15}$	0,125
Potentilla crantzii	$0.23_{1,16}$	0,642	$1.65_{1,16}$	0,219	$0.64_{1,16}$	0,435			$0.00_{1,16}$	0,978	$0.01_{1,16}$	0,940	$0.19_{1,16}$	0,665	$2.23_{1,16}$	0,156
Thalictrum alpinum	$7.21_{1,18}$	**0,016**	$0.39_{1,18}$	0,540	$0.02_{1,18}$	0,903			$0.53_{1,18}$	0,477	$0.85_{1,18}$	0,369	$0.35_{1,18}$	0,561	$1.57_{1,18}$	0,228
Antennaria dioica	$3.29_{1,12}$	**0,097**	$0.48_{1,12}$	0,503	$1.97_{1,12}$	0,188			$1.42_{1,12}$	0,259	$0.31_{1,12}$	0,590	$1.24_{1,12}$	0,289	$0.82_{1,12}$	0,385
Luzula spicata	$0.7_{1,18}$	0,415	$1.41_{1,18}$	0,251	$0.64_{1,18}$	0,435	$0.13_{1,18}$	0,723			$0.00_{1,18}$	1,000	$0.00_{1,18}$	0,985	$0.91_{1,18}$	0,353
Bistorta vivipara	$0.98_{1,19}$	0,336	$0.57_{1,19}$	0,459	$0.05_{1,19}$	0,820			$1.16_{1,19}$	0,297	$0.16_{1,19}$	0,691	$0.04_{1,19}$	0,846	$1.41_{1,19}$	0,250
Festuca vivipara	$15.37_{1,19}$	**0,001**	$0.47_{1,19}$	0,502	$0.11_{1,19}$	0,750	$1.67_{1,19}$	0,212			$0.01_{1,19}$	0,919	$24.33_{1,19}$	**0,000**	$0.00_{1,19}$	0,957

Regarding the mean values of functional traits, individual responses of species *Cerastium alpinum, Parnassia palustris, Luzula spicata* showed also a significant difference in OTCs plots in height in comparison with C plots.

The species that responded the most to simulated climate warming in OTCs plots was *Carex capillaris,* which showed, in addition to the height, a significant increase in both length of the longest leaf, and leaf area (see Figure A, B). *Festuca vivipara*, was the only species responding positively to warming in biomass (see Figure C). *Cerastium alpinum* showed a negative response to warming with a close to significant decrease in number of leaves (see Figure D).

Figure 2. Results of one way ANOVAs on the effects of climate warming in C vs OTCs plots at alpine Finse for species: *Carex capillaris*; length of the longest leaf (Fig. A), *Carex capillaris*; leaf area (Fig. B), *Festuca vivipara*; biomass (Fig. C), *Cerastium alpinum*; number of leaves (Fig. D).



Mean length of the longest leaf was more significant in OTCs plots than in C plots for species *Cerastium alpinum, Parnassia palustris, Thalictrum alpinum, Antennaria dioica, Luzula spicata and Bistorta vivipara.* Species *Parnassia palustris Potentilla crantzii, Thalictrum alpinum, Antennaria* *dioica* and *Festuca vivipara* showed a significant increase in number of leaves under warmer temperature in OTCs plots. All three graminoids in my study reached a significant difference in OTCs plots in number of fruit/seeds compared to C plots. Only two species; *Cerastium alpinum* and *Bistorta vivipara* responded to climate warming with increased number of flowers in OTCs plots, whereas *Bistorta vivipara* responded much more positively than *Cerastium alpinum.* Less remarkable, but still positive responses to warming were observed within leaf area for species *Parnassia palustris, Thalictrum alpinum* and *Bistorta vivipara.* Within biomass, *Parnassia palustris, Potentilla crantzii, Antennaria dioica* and *Luzula spicata,* responded also less significantly, but still positively reaching greater biomass in OTCs plots than in C plots. Specific leaf area among the species in OTCs plots was significantly greater than in C plots for *Cerastium alpinum, Parnassia palustris, Carex capillaris, Potentilla crantzii* and *Thalictrum alpinum.*

The results of correlation indicate a strong positive correlation between height and biomass within 7 of the study species, i.e. *Erigeron uniflorus, Parnassia palustris, Carex capillaris, Potentilla crantzii, Luzula spicata, Bistorta vivipara* and *Festuca spicata*. A significant correlation between height and length of the longest leaf was observed within *Carex capillaris, Thalictrum alpinum* and *Bistorta vivipara*. *Antennaria dioica* was the only species that showed no significant correlation within height at all.

Discussion

Some of the study species clearly responded to experimental warming in the *Dryas* heath at alpine Finse. This study found significant positive effects of warming on plant *height* for most of the study species. This functional trait seems to be the most plastic. When the functional traits of a species demonstrate more adaptive plasticity, this is likely to help that species adapt to changing conditions (Nicotra et al. 2010).

Klanderud (2008) suggests that tall growing species can potentially outcompete low growing species at alpine Finse. The study further suggests that there is no clear presumption of species responses within a functional type. This corresponds with my study where the graminoids *Festuca vivipara* and *Carex capillaris* showed a significant, even identical ratio in height within OTCs plots, while *Luzula spicata* belonging to graminoids as well, didn`t respond. To consider this more specifically, *Festuca vivipara* belongs to Grass family; *Poaceae* and *Carex capillaris* belongs to Sedge family; *Cyperaceae* whereas *Luzula spicata* belongs to Rush family*; Juncaceae.* All three differ from each other in numerous ways although they all belong to Grass family. Grasses can be, for instance, either annual plants (www1), i.e. they complete their life time in one season, or perennial plants, i.e. they live more than two years and may produce seed each season, while sedges are all perennials.

The strongest response to experimental warming in my study showed *Carex capillaris* that is exactly in line with a similar study (conducted by Clara Elisabeth Spilling, bachelor thesis UiA) in the same time at the same place, approximately 100 metres under my study area. Her results suggest increased height and amount of leaves within mentioned species. The latter functional trait does not correspond with my study, but there may be some unintended differences when the leaves were counted. Increased abundance of *Carex capillaris* is in line with the study of the effects of a seed-addition conducted by Siri Lie Olsen (PhD-student at UMB, Ås) at the same study area as mine. These responses may suggest that *Carex capillaris* may have a good potential for fast growth, and hence successful adapting in the face of climate warming. This is in line with other studies suggesting that graminoids are good competitors and may adapt to climate warming more easily (e.g. Klanderud and Totland 2005).

The increased height of *Thalictrum alpinum* from Clara Elisabeth Spilling`s study also corresponds with my results and also with the previous study where this species increased height under simulated warming (Klanderud and Totland 2005). Results from Siri Lie Olsen suggest as well that *Thalictrum alpinum* increased in abundance in OTCs plots. *Thalictrum alpinum* along with *Antennaria dioica* were the only species that showed among all forbs in my study a significant positive response to experimental warming in height. This may point out that *Thalictrum alpinum* may face positively to future climate changes.

A significant positive height for *Festuca vivipara* in OTCs plots corresponds with the previous study where a four years experimental warming increased the abundance of above mentioned species (Klanderud 2008). Klanderud and Totland (2007) observed that species establishment decreased when graminoids increased in abundance. On the other hand, Klanderud (2008) observed a decrease in abundance of some *Carex* species after four years of warming. This suggests that species responses to climate warming may vary over time.

A recent meta study of tundra vegetation responses to experimental warming (Elmendorf et al. 2012), found also an increased abundance of graminoids in regions with colder climate. This is in accordance with my results because both *Carex capillaris* and *Festuca vivipar*a, belonging to graminoids, showed a positive response to climate warming within height reaching a very significant difference in comparison with the responses of the other forbs. Kudernatsch et al. (2008) suggests also a stronger response of graminoids compared to herbaceous perennials under simulated warming. This may predict that these competitive grasses will outcompete forbs and thus gradually dominate the plant community.

Klanderud and Totland (2007) suggest that warmer temperature can increase the role of interspecific competition in alpine regions. Consequently, this reflects the fact that abundance of dominant species determines the plant community dynamics due to altered interactions (Klanderud and Totland 2005).

Cornelissen et al. (2003) suggests that height tends to correlate with other size traits, e.g. biomass and leaf size that is in line with my results.

In addition to height, it seems that length of the longest leaf and amount of leaves also perform as important factors in relation to responses of climate warming, and subsequently biomass and specific leaf area act as important respondents within functional traits.

Because of such different individual responses, I observed no clear prediction of future responses of species in this study. It is possible that both potential “winner” and “loser” species may face future climate change equally. That is to say, the species that seems to have a better ability to survive in warmer temperature may decrease in abundance over time, and species that are predicted to decrease in abundance under climate warming pressure may turn into potential winners. As the species from lower regions move upward, thus increasing the cover abundance of the plant community, it is height that becomes the most important factor towards achieving territorial competitive advantage, and thus likely dominating vegetation composition in the long term.

Conclusion

The enhanced temperature is undoubtedly a key factor for plant growth in alpine regions. The observed increase in height under experimental warming may point out that this functional trait is among others the most plastic and therefore species managing to grow taller will likely adapt to climate warming more easily at the expanse of low stature species. Through the evaluating of individual functional traits of selected study species, this study further demonstrates that there may be different responses to increasing temperature within a functional type and it may be challenging to predict responses of species to future climate warming. However, on the basis of aggregated data, this study may suggest that there is a possible prediction that alpine regions may be dominated by graminoids in future.

Plants respond to climate warming differently over time and thus continuing research is needed to understand the complexity of mountain plant community. It is my hope that my study has contributed to our emerging understanding and knowledge on the effects of climate change on alpine plant species.

The Earth is like a puzzle that was given to us and climate change is one piece of this puzzle. If we ignore the importance of that one piece and let it disappear, then we will no longer have the puzzle that we call Earth.

Literature

Arft, A. M., Walker, M. D., Gurevitch, J., Alatalo, J. M., Bret-Harte, M. S., Dale, M., Diemer, M., Gugerli, F., Henry, G. H. R., Jones, M. H., Hollister, R. D., Jonsdottir, I. S., Laine, K., Levesque, E., Marion, G. M., Molau, U., Molgaard, P., Nordenhall, U., Raszhivin, V., Robinson, C. H., Starr, G., Stenstrom, A., Stenstrom, M., Totland, O., Turner, P. L., Walker, L. J., Webber, P. J., Welker, J. M., Wookey, P. A . (1999). Responses of tundra plants to experimental warming: Meta-analysis of the International Tundra Experiment. *Ecological Monographs,* 69: 491-511.

Aune, B. (1993). Temperaturnormaler: normalperioder 1961-1990. Det Norske meteorologiske institutt, Oslo. Norway.

Beniston, M., Fox, D. G., Adhikary, S., Andressen, R., Guisan, A., Holten, J., Maitima, J., Price, M., and Tessier, L.: (1995). The Impacts of Climate Change on Mountain Regions, Second Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), Chapter 5, Cambridge University Press, Cambridge.

Cornelissen, J. H. C., Lavorel, S., Garnier, E., Diaz, S. et al. (2003). Handbook of protocols for standardised and easy measurement of plant functional traits worldwide. Aust. J. *Bot*. 51: 335-380.

Elmendorf, S. C., G. H. R. Henry, R. D. Hollister, R. G. Bjork, A. D. Bjorkman, T. V. Callaghan, L. S. Collier, E. J. Cooper, J. C. H. Cornelissen, T. A. Day, A. M. Fosaa, W. A. Gould, J. Gretarsdottir, J. Harte, L. Hermanutz, D. S. Hik, A. Hofgaard, F. Jarrad, I. S. Jonsdottir, F. Keuper, K. Klanderud, J. A. Klein, S. Koh, G. Kudo, S. I. Lang, V. Loewen, J. L. May, J. Mercado, A. Michelsen, U. Molau, I. H. Myers-Smith, S. F. Oberhauer, S. Pieper, E. Post, C. Rixen, C. H. Robinson, N. M. Schmidt, G. R. Shaver, A. Stenstrom, A. Tolvanen, O. Totland, T. Troxler, C. H. Wahren, P. J. Webber, J. M. Welker and P. A. Wookey. (2012). Global assessment of experimental climate warming on tundra vegetation: heterogeneity over space and time. *Ecology Letters,* 15: 164-175.

Klanderud K. *&* Totland Ø. (2007). The relative role of dispersal and local interactions for alpine plant community diversity under simulated climate warming. *Oikos*, 116, 1279–1288.

Klanderud, K. (2008). Species-specific responses of an alpine plant community under simulated environmental change. *Journal of Vegetation Science,* 19: 363-372.

Klanderud, K. & Totland, Ø. (2005). Simulated climate change altered dominance hierarchies and diversity of an alpine biodiversity hotspot. *Ecology,* 86*:* 2047–2054.

Klanderud, K. & Totland, Ø. (2005) The relative importance of neighbours and abiotic environmental conditions for population dynamic parameters of two alpine plant species. *Journal of Ecology,* 93: 493-501.

Klanderud, K. & Birks, H. J. B. (2003). Recent increases in species richness and shifts in altitudinal distributions of Norwegian mountain plants. *The Holocene,* 13: 1-6.

Kudernatsch, T., Fischer, A., Bernhardt-Romermann, M., Abs, C. (2008). Short-term effects of temperature enhancement on growth and reproduction of alpine grassland species. *Basic and Applied Ecology,* 9: 263-274.

McMullen, C. P. . & Jabbour, J. (2009). Climate Change Science Compendium. (2009). Nairobi: United Nations Environment Programme, EarthPrint.

Michelsen, O., Syverhuset, A. O., Pedersen, B., Holten, J. I. (2011). The Impact of Climate Change on Recent Vegetation Changes on Dovrefjell, Norway. *Diversity, 3*: 91–111.

National Science Foundation (NSF), (2009). Solving the puzzle, researching the impacts of

climate change around the world. http://www.nsf.gov/news/nsf09202/nsf09202.pdf

Retrieved 12.4.2012

Nicotra A. B, Atkin O. K., Bonser S. P. , Davidson A. M., Finnegan E. J., et al. (2010). Plant phenotypic plasticity in a changing climate. *Trends in Plant Science*, 15: 684–692.

Pauli H., Gottfried M., Grabherr G. (2003). Effects of climate change on the alpine and nival vegetation of the Alps. *Journal of Mountain Ecology*, 7 (Suppl.), 9-12.

Pellissier, L., Fournier, B., Guisan, A., Vittoz , P. (2010). Plant traits co-vary with altitude in grasslands and forests in the European Alps. *Plant Ecology*, 211: 351-365.

Rammig, A., Jonas, T., Zimmermann, N. E., Rixen, C. (2010). Changes in alpine

plant growth under future climate conditions. *Biogeosciences*, 7: 2013–2024.

The Norwegian Meteorological Institute (2010). eKlima. Data from weather station 25840 at Finse, normal period 1961-1990. To be found on the web page http://eklima.met.no Retrieved 20.04.2012.

Vile D., Garnier E., Shipley B., Laurent G., Navas M. L., Roumet C., Lavorel S., Díaz S., Hodgson J. G., Lloret F., Midgley G. F., Poorter H., Rutherford M. C., Wilson P. J., Wright I. J. (2005). Specific leaf area and dry matter content estimate thickness in laminar leaves. *Annals of Botany*, 96: 1129–1136.

Walther, G. R., Beißner S., Pott R. (2005). Climate change and high mountain vegetation shifts. In: Broll, G. & Keplin, B. (eds.) *Mountain ecosystems – Studies in treeline ecology*, pp. 77–96. Springer, Heidelberg, DE.

Weiher, E., van der Werf, A., Thompson, K., Roderick, M., Garnier, E., Eriksson, O. (1999). Challenging Theophrastus: A common core list of plant traits for functional ecology. *Journal of Vegetation Science,* 10: 609-620.

www1: http://plants.usda.gov/java/profile?symbol=CACA12 Retrieved 02.05.2012

Appendix 1

Table 1. Mean values of functional traits for nine selected species in control (C) and open top chambers (OTC) plots at Finse, alpine southern Norway.

Species	Height		Length of longest l.		Number of leaves		Number of fruit/seeds		Number of flowers		Leaf area		Biomass		Specific leaf area	
	C	OTC	C	OTC	C	OTC	C	OTC	C	OTC	C	OTC	C	OTC	C	OTC
Cerastium alpinum	**68,15**	69,50	8,21	8,33	**2,46**	1,65			1,00	1,25	**0,29**	0,26	**0,04**	0,04	124,15	132,80
Erigeron uniflorus		83,30		17,00		12,25						0,30		0,08		166,10
Parnassia palustris	20,20	62,70	6,20	10,23	4,00	6,00			1,00	1,00	0,11	0,49	0,01	0,03	114,00	145,07
Carex capillaris	29,68	**64,96**	26,80	**36,77**	5,83	5,10	9,83	**12,10**			0,22	**0,32**			101,00	**124,70**
Potentilla crantzii	60,08	56,99	14,01	11,80	4,25	5,00			2,13	2,11	1,48	1,46	0,08	0,09	83,47	97,20
Thalictrum alpinum	47,39	**64,54**	10,27	11,06	3,22	3,30			7,44	6,90	0,50	0,60	0,03	0,02	86,12	109,30
Antennaria dioica	55,38	**73,51**	8,38	9,47	10,00	**22,14**			3,50	2,86	0,21	0,17	0,05	0,07	134,90	113,92
Luzula spicata	110,80	**127,70**	29,63	34,05	3,33	3,00	18,00	18,90			0,28	0,28	0,05	0,06	81,90	68,45
Bistorta vivipara	54,08	**47,25**	22.07±3.13	25,20	2,00	1,90			6,50	10,10	1,07	1,14	0,04	0,04	100,61	95,44
Festuca vivipara	119,20	**185,90**	45,98	41,18	4,90	5,30	8,10	9,10			0,09	0,09	0,04	0,06	24,22	23,94

Appendix 2

Table 2. Results of correlation of functional traits in control (C) and open top chambers (OTC) plots at alpine Finse.

Species		Height	Length of the longest leaf	Number of leaves	Number of fruit/seeds	Number of flowers	Leaf area	Biomass
		P	P	P	P	P	P	P
Cerastium alpinum	Length of longest leaf	0,335						
	Number of leaves	0,834	0,620					
	Number of flowers	0,571	0,558	0,166				
	Leaf area	0,058	0,336	0,450		0,359		
	Biomass	0,179	0,789	0,499		0,152	0,374	
	Specific leaf area	**0,006**	0,552	0,829		0,979	0,193	0,371
Erigeron uniflorus	Length of longest leaf	0,401						
	Number of leaves	0,284	0,857					
	Number of flowers							
	Leaf area	0,984	0,198	0,746				
	Biomass	**0,041**	0,574	0,119			0,864	
	Specific leaf area	0,833	0,319	0,460			0,377	0,884
Parnassia palustris	Length of longest leaf	0,112						
	Number of leaves	**0,046**	**0,015**					
	Number of flowers							
	Leaf area	0,072	0,346	0,775				
	Biomass	**0,091**	**0,027**	**0,022**			0,285	
	Specific leaf area	0,238	0,589	0,442			0,074	0,452
Carex capillaris	Length of longest leaf	**0,000**						
	Number of leaves	**0,048**	0,367					
	Number of fruit/seeds	0,059	0,217	0,223				
	Leaf area	**0,004**	**0,015**	0,492	**0,014**			
	Biomass	**0,034**	0,091	0,551	**0,021**		**0,000**	
	Specific leaf area	0,255	0,414	0,949	0,160		**0,002**	0,085
Potentilla crantzii	Length of longest leaf	0,188						
	Number of leaves	0,256	0,772					
	Number of fruit/seeds							
	Number of flowers	0,151	**0,004**	0,929				
	Leaf area	**0,040**	**0,002**	0,673		**0,002**		
	Biomass	**0,050**	**0,009**	0,632		**0,000**	**0,000**	
	Specific leaf area	0,998	0,722	0,128		0,408	0,798	0,916
Thalictrum alpinum	Length of longest leaf	**0,092**						
	Number of leaves	0,755	0,698					
	Number of flowers	0,067	0,285	0,933				
	Leaf area	0,263	**0,001**	0,292		0,931		
	Biomass	0,651	0,239	**0,000**		0,214	**0,028**	
	Specific leaf area	0,409	0,247	0,753		0,614	0,548	0,381

Antennaria dioica	Length of longest leaf	0,093						
	Number of leaves	0,537	0,482					
	Number of flowers	0,599	0,435	0,657				
	Leaf area	0,815	0,422	0,703		0,190		
	Biomass	0,717	0,620	**0,001**		0,504	0,403	
	Specific leaf area	0,993	0,653	0,457		0,108	**0,000**	0,593
Luzula spicata	Length of longest leaf	0,947						
	Number of leaves	0,057	0,523					
	Number of fruit/seeds	**0,006**	0,741	0,834				
	Leaf area	0,950	**0,031**	0,805	0,308			
	Biomass	**0,018**	0,143	0,483	**0,001**		0,065	
	Specific leaf area	0,713	0,453	0,920	0,874		**0,000**	0,855
Bistorta vivipara	Length of longest leaf	**0,008**						
	Number of leaves	0,140	**0,019**					
	Number of flowers	0,220	**0,017**	0,884				
	Leaf area	0,192	0,081	0,759		**0,009**		
	Biomass	**0,025**	**0,017**	0,799		**0,008**	**0,000**	
	Specific leaf area	0,885	0,763	0,135		0,697	0,271	0,292
Festuca vivipara	Length of longest leaf	0,680						
	Number of leaves	0,312	0,064					
	Number of fruit/seeds	0,140	0,947	0,121				
	Leaf area	0,508	0,213	0,193	0,512			
	Biomass	**0,037**	0,233	0,469	**0,017**		0,990	
	Specific leaf area	0,387	**0,041**	0,490	0,540		**0,012**	0,962